Fourth Industrial Revolution Research Outputs in Africa: A Bibliometric Review

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Abstract. The world is currently transitioning through the fourth industrial revolution (4IR) era. 4IR research outputs are growing exponentially. Although African governments have been promoting fourth industrial revolution research and making initiatives to leverage it, these research outputs have not been analyzed. There is a dearth of publications that provide an up-to-date overview and a knowledge mapping analysis of 4IR literature in Africa. For this study, a bibliometric analysis of 912 scholarly papers published in Web of Science (WoS) core collection was conducted to reflect the research trends, 4IR themes, and gaps in 4IR publications in Africa. VOSviewer software was used to analyze the data. The results indicate that there has been a gradual growth in 4IR publications in Africa with a peak of 227 publications in 2021 according to the WoS database. South Africa is the most contributing and collaborative country, with most publications produced by the University of Johannesburg. The results suggest limited collaborations among African institutions and authors in this field. The 4IR research hotspots as revealed by keywords co-occurrences in Africa include machine learning, cloud computing, remote sensing, big data, and internet of things mainly for predictions and classification. The areas that may have received the least research focus include smart cities, block-chain, ecosystem service, policy, health care, and precision agriculture. By highlighting the research trends and gaps in 4IR literature in Africa, this study suggests possible directions for future 4IR research.

Keywords: Fourth industrial revolution · bibliometric analysis · research trends · 4IR trending technologies · Africa

1 Introduction

Fourth Industrial revolution, also known as industrial 4.0 or 4IR conceptualizes the 21st century's rapid transformation in technology, profound shift in production, business models and processes, transportation, and service delivery fostered by the blurring of the boundaries between the digital, physical, and biological domains [1, 2]. Industrial revolutions are the transformations in the systems and technology that surround humans and the way humans interact with these systems and technology, which in turn shape the ways of perceiving, acting, and being [1]. The first industrial revolution was a major innovation in the late 1700s and early 1800s [3]. It was a shift from handicraft economy

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to machine-powered economy characterized by using steam engines and mechanical manufacturing for production of goods and services [3]. The second industrial revolution or technological revolution made its debut in 19th centuries [4]. This revolution marked the shift from mechanical manufacturing and steam engine to electronic technology for mass production. The invention of assembly lines in the second revolution resulted in exponential growth in the industrial sector [2]. The second industrial revolution was followed by the third industrial revolution also known as digital revolution, in 20th century. This revolution was punctuated by a transition from the analogue electronic technology to the digital electronics [2, 5]. In third industrial revolution Information Technology and electronics were used to automate the production processes [6]. This phase of industrial revolution marked the era of information age, information systems-based economy [5]. The fourth industrial revolution emerged in the 21st century. The hallmark of the fourth industrial revolution is the remarkable upsurge in technological breakthroughs, their unlimited scope of application, and their tremendous impact in reshaping the way of living [7]. One of the prominent features of 4IR is the capability of the new technology to fuse the physical, biological, and digital world [8]. Some of the eminent and powerful technologies that have made a great mark in 4IR include artificial intelligence, machine learning, Internet of Things (IoT), quantum computing, robotics, 3-D printing, cloud computing, big data, and augmented reality [2, 7–9]. Even though each industrial revolution may be seen as individual entity, each industrial revolution is rather an advancement of the previous one.

The inexorable changes brought by fourth industrial revolution on nearly the entire gamut of human's life has attracted attention of several researchers globally [1, 3, 7, 8, 10–15], resulting in rich literature around 4IR. Literature on 4IR range from the application and use of 4IR in different sectors such as education, health, industries, agriculture, governance etc., to review papers. For instance, [16] explored the use of machine learning in agriculture, while [15, [17–23] used artificial intelligence and machine learning in health. On the other hand, [24] used IoT in in agriculture, [25] used IoT in the optimization of the state management of economy, while [13, 26–37] conducted systematic review studies in 4IR in different disciplines.

In Africa, governments and institutions have been promoting fourth industrial revolution research and making initiatives to leverage it [38]. Consequently, there are several research studies on 4IR conducted in Africa to tackle some of the prominent challenges that Africa face such as drought, diseases, and food security [39–41]. For instance, [42] used machine learning to optimize cropping farming by small scale farmers, [15] utilized machine learning to predict malaria, and [40, 43] used artificial neural networks to predict drought. There are also studies in Africa that focus on the challenges and opportunities of 4IR in Africa [10, 12]. However, previous studies reported low contribution of Africa in the research output [44, 45]. Limited research output in Africa is in part impacted by poor infrastructure [46], brain drain of African expertise [47], insufficient funds for research studies [46, 48, 49], African researchers having high teaching loads and receiving little incentives [48], and inadequate research collaboration networks [50]. Faced with these opportunities and challenges in 4IR Africa, there is a little known about the development in the 4IR research output in Africa.

To provide a comprehensive analysis of the 4IR literature in Africa, some authors proposed review studies [51–53]. However, most of these review papers are systematic reviews focusing mainly on the comprehensive analysis of the content of the publications and a few focus on the bibliometric analysis. A bibliometric analysis provides an overview and a knowledge mapping of the literature in a specific research area [54]. There have been several bibliometric analyses in other geographical areas outside Africa or on isolated 4IR technologies. For example,[55] focused on the bibliometric review of Machine learning on COVID-19, while [11, 56, 57] focused on bibliometric review of 4IR on supply chain, knowledge management, and agriculture 4.0, respectively. Bibliometric analysis to review 4IR has not been fully exploited, especially in African context. Therefore, this research study focuses on bibliometric analysis on fourth industrial revolution publications to explore research developments in this field in Africa. Bibliometric analysis on fourth industrial revolution can unpack the status of fourth industrial revolution literature in Africa: research and technological trends, hot spots areas as well as the gaps.

Given the above research gap, this paper aims at answering the following research question:

What is the current state of the fourth industrial revolution literature in Africa?

To answer the above questions the following research objectives were demarcated:

1. To characterize the current state of the fourth industrial revolution research in Africa.
2. To identify trends in fourth industrial revolution research related to Africa.
3. To identify the technological trends in fourth industrial revolution research in Africa
4. To identify the research gaps and opportunities in fourth industrial revolution in Africa.

This paper proceeds as follows: Sect. 2 outlines research methodology, and Sect. 3 evaluates publication trends and identifies emerging themes in fourth industrial revolution. The fourth section focuses on the assessment of gaps and possible research opportunities in the fourth industrial revolution in Africa. Lastly, Sect. 5, concludes the paper by detailing the study's main contribution.

2 Material and Methods

The dataset used in this research study was extracted from WoS. Web of Science is one of the most widely used standard indexes in the computer science and engineering community [58]. The search was conducted with all time span (All years (1996 – 07/08/2022)). Though there were no restrictions on language or document type, the geographic scope of publication was restricted to Africa. The search was done at the topic level which searches for the match in the paper title, abstract and keywords. The following search string was used to get the dataset:

TS = ("Industry 4.0*" OR '4IR' OR "Fourth industrial revolution" OR "machine learning" OR "artificial intelligence" OR "big data" OR "Internet of Things" OR 'IoT' OR "quantum computing" OR 'robotics' OR "3D printing" OR "cloud computing" OR "augmented reality" OR "Block chain") AND TS = ("Africa").

The search resulted in 1 663 papers from Web of Science. The dataset comprised of the following bibliographic meta data of the retrieved papers and their cited papers:

information about authors, document, content, citation, and funding. To improve the data quality. The documents were further screened manually at the tittle, abstract and where required at the full paper level. Papers that did not meet the inclusion criteria were removed. The inclusion criteria were that the paper should be on any technology in fourth industrial revolution (artificial intelligence, IoT, machine learning, cloud computing, etc.,) and conducted in Africa. Nine duplicates were also removed. After this manual screening, there were 924 papers that met the inclusion criteria. Figure 1 below shows the search process of identifying papers for inclusion.

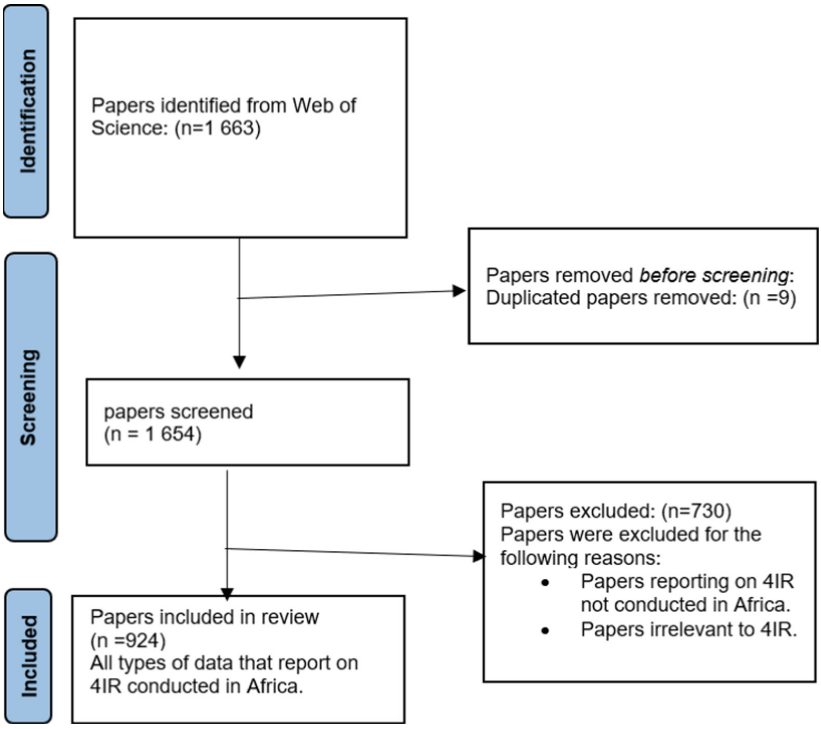

Fig. 1. Process of identifying papers for inclusion.

The dataset was then analyzed using VOSviewer version 1.6.18 to create visualization maps. Visualization maps play a critical role in describing the structure and evolution of a certain research field. VOSviewer is a widely used efficacious tool for bibliometric analysis. For example, [59] used VOSviewer to provide a knowledge mapping analysis of the prediction of infectious diseases literature. On the other hand, [60] used VOSviewer to explore methods and tools used to monitor and predict drought in Africa, while [61] and [62] deployed VOSviewer to quantify the research output on Ebola virus and COVID-19, respectively. In this study, VOSviewer was used to determine the research trends, gaps, and future research opportunities in the field of fourth industrial revolution in the context of Africa, and the following maps were created: co-citation, keywords co-occurrence, and co-authorship maps.

3 Results

3.1 The Fourth Industrial Revolution Research Trends in Africa

Evolutionary Trajectories of Publications in Fourth Industrial Revolution in Africa
Figure 2 depicts the number of publications in fourth industrial revolution in Africa from 2011 to 2022. The year with the highest publications is 2021 while 2011 is the year with the lowest publications It can be observed that from 2011 to 2014, the literature on fourth industrial revolution was very sparse. The significant increase in the number of publications started from 2016 and 2017 with an increase of 4.93% and 7.34%, respectively. An upsurge in publications was also observed from 2019, 2020 to 2021 with publication increase of 13.9%, 18.2% and 24.8%, respectively. The apparent decline in 2022 publications could be explained by the fact the data collection for only up to 8 August 2022. Overall, there has been slow but notable increase in the yearly publications in this field in Africa, from 2011to 2022, this is demonstrated by the approximate 2.3% annual average growth rate. Additionally, it can be observed that the number of citations has grown exponentially and has surpassed the number of the publications. This is an indication of the influence and impact of these publications.

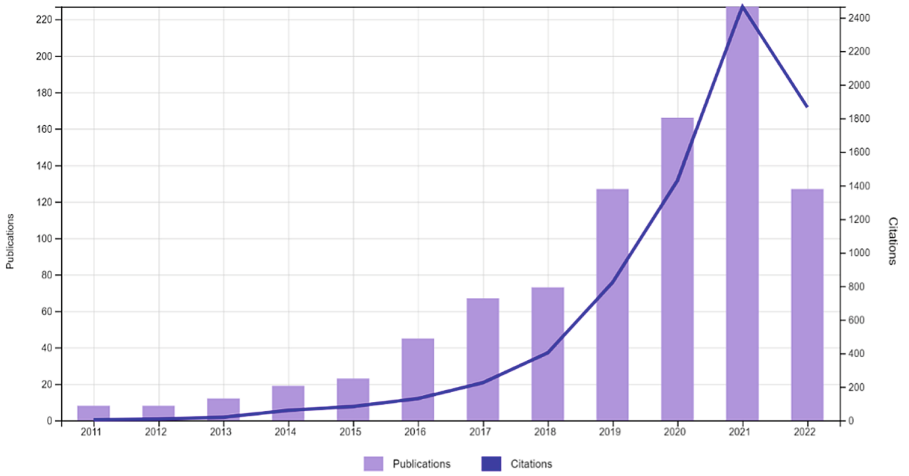

Fig. 2. The number of publications and citations' evolutionary trajectories in fourth industrial revolution in Africa from 2011 to 2022.

Document Types of Fourth Industrial Revolution Publications in Africa
Table 1 illustrates different types of documents that were considered for further analysis after the manual screening. It can be noted that the dataset consists mainly of articles, and conference papers followed by review articles. Books, news items and letters were the least presented papers in the dataset.

Table 1. Document types of the fourth industrial revolution publications in Africa.

Document Types	Record Count	Percentage of 912
Article	620	67.98
Proceeding Paper	236	25.88
Review Article	42	4.61
Early Access	29	3.18
Book Chapters	18	1.97
Editorial Material	18	1.97
Meeting Abstract	6	0.66
Data Paper	3	0.33
Letter	3	0.33
Book	1	0.11
News Item	1	0.11

Web of Science Categories

The 4IR publications in Africa as per the dataset come from different disciplines such as Economics and Infectious Diseases. Figure 3 shows different WoS categories or disciplines in the development of fourth industrial revolution research in Africa. The WoS categories that had a minimum of 20 research outputs were considered in the graph. It can be observed that documents in fourth industrial revolution in Africa were from the environmental science, followed by Remote Sensing, Computer Science Theory Methods, Image Science Photographic Technology, Telecommunications and Multidisciplinary Science. The results (not depicted in the graph) show that there are 25 WoS disciplines that may be under-represented in 4IR literature as they each only have one publication in 4IR. These disciplines include Sport Sciences, Nuclear Science Technology, History, Criminology Penology, Family Studies, and Pharmacology Pharmacy.

Top Ten Most Productive Countries in Fourth Industrial Revolution Literature in Africa

Several countries have contributed to 4IR publications in Africa, and Fig. 4 shows the top leading countries. Countries were ranked based on the first author's country of affiliation, and only the top 10 countries were considered.

South Africa is the leading country in publications on fourth industrial revolution in Africa, accounting for 49.9% of the publications. South Africa is followed by the United States of America (USA), England, Germany, and Kenya. Europe is the mostly represented continent in the top 10 and it is represented by four countries. The top ten list has got three African countries (South Africa, Kenya, and Nigeria) and two American countries (USA and Canada). The continent that is least represented is Asia while other continents such as Oceanica are not represented at all.

The Most Productive Authors

There are several authors who have contributed to the 4IR literature in Africa. Figure 5

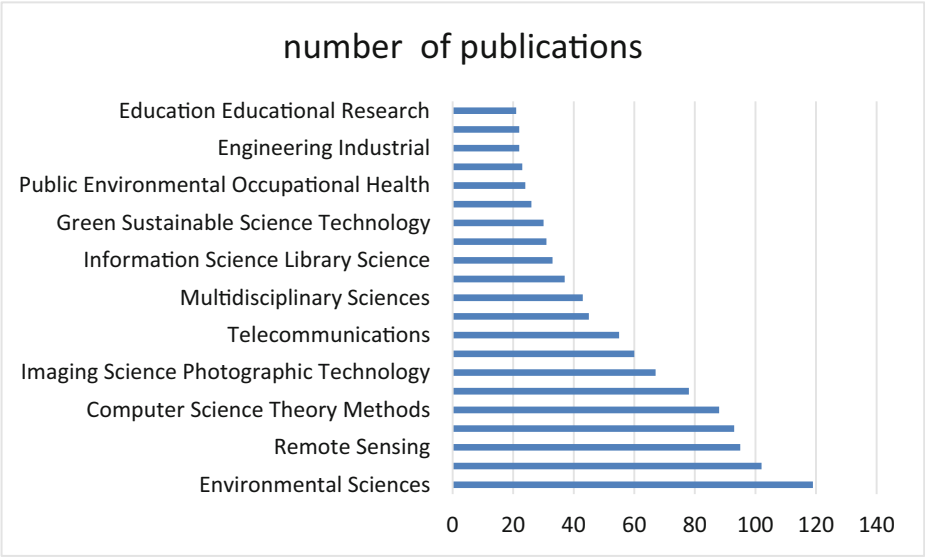

Fig. 3. Top 10 most publishing WoS categories in 4IR research in Africa.

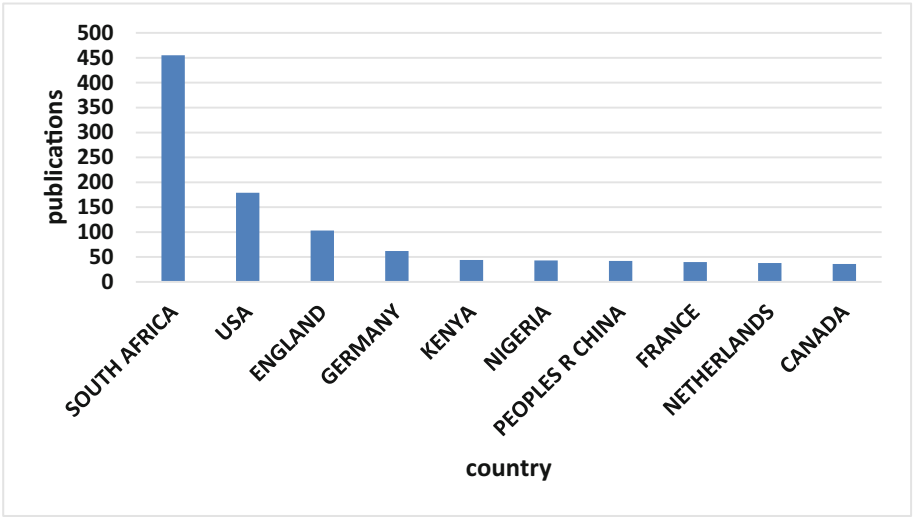

Fig. 4. Top 10 most productive countries in fourth industrial revolution publications in Africa.

illustrates the top 10 most contributing authors in this field. At the top is Bag. S, followed by Muntanga. O, Adam. E, Dube. T, Hasan. AN., and Stopforth, R. All the authors in the top 10 have at least seven papers published in this field.

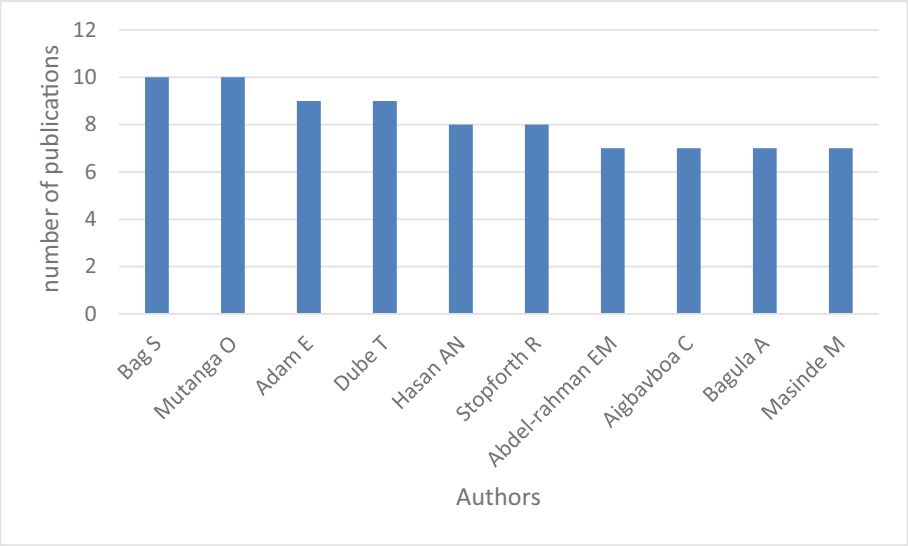

Fig. 5. Top 10 most contributing authors in fourth industrial revolution publications in Africa.

3.2 VOSviewer Visualization Maps

A VOSviewer map consists of nodes which are also called circles or items, and edges that connect the nodes. A node represents the item of interest in the map while the edge indicates the relationship between two nodes that it connects [63]. For instance, in the authors co-authorship map, the items of interest will the authors and an edge connecting two authors would indicate collaboration between those authors. The items with strong relatedness are grouped in one cluster and are given the same color [63].

Country Collaboration Map

Country co-authorship map illustrates the number of co-authored documents between countries and, therefore, reflects the strength or extend of collaborations among the countries [63]. Figure 6 below depicts the VOSviwer visualization map of country collaboration.

The map groups countries with high collaboration in the same cluster. The countries denoted with bigger circles indicate dominating countries in the fourth industrial revolution literature in Africa. These countries include South africa, the USA and England. These countries also appeared in Fig. 4 as top 10 leading countries in number of research outputs. It can be noted that these countries also tended to be more collaborative. South Africa is the most collaborative country in 4IR publications with the total collaboration strength of 289. South Africa is followed by the USA, England, Germnany and France. South Africa collaborates with both countries abround and in Africa. The other countries with a strong collaborative strength in Africa include Kenya, Tanzania, Ghana, Ethopia, and Nigeria, each with a collaboration total strength of 105, 79, 66, 63 and 62, respectively. Non African countries that show strong collaborations include India, People Republic of China and Neverlands. On the other hand, the least collaborating countries

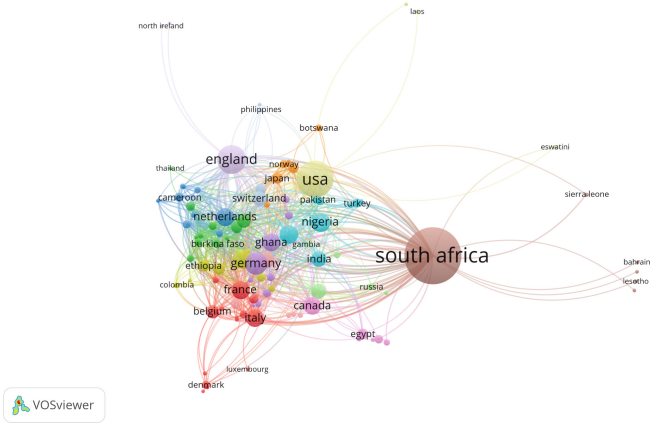

Fig. 6. Country collaboration in fourth industrial revolution publications in Africa.

include Lesotho, Mauritius, Tunisa and Zwaziland. These countries have mostly collaborate with South Africa. They are also the least contributing countries in this field; this is denoted by the small circles that represent these countries in the visualization map.

In this map, there are 14 clusters. The biggest cluster with the most countries is the red cluster consisting of 14 countries that include France, Mali, Guinea Bissau, Morocco and Ukraine. Even though South Africa is clustered with countries like Lesotho, Sierra Leon and Mariatius, it also shows a very strong collaboration with countries such as the USA, England and Ghana. The cluster with the smallest number of the countries is the purple clustered consisting of Peru, England and Northern Ireland.

Institution Collaboration Map

There are 1331 institutions that contributed to 4IR literature in Africa according to the WoS database. Figure 7 shows the institution collaboration map which indicates the co-authorship among the institutions on 4IR literature in Africa. The relatedness of the items (institutions) is based on the number of papers co-authored [63]. Only institutions meeting the default threshold of five co-authored documents per an institution were considered, and consequently, 62 institutions were included in the map.

Institutions with the strong collaboration among themselves are clustered together and there are 10 clusters in this map. The red cluster is the biggest cluster and comprised of institutions such as the University of Ghana, the University of Maryland and NASA. The dark blue cluster shows the collaboration among South African institutions only. The purple cluster also depicts collaboration mainly between the South African institutions, with the University of Nairobi as well as the University of Antwerp. Similar observations can be made on the light blue cluster (containing the University of Johannesburg) and the orange cluster (showing the University of KwaZulu Natal), South African institutions dominate the clusters and are the most collaborative institutions among themselves and with other institutions. Table 2 illustrates the top 10 most contributing institutions in 4IR in Africa.

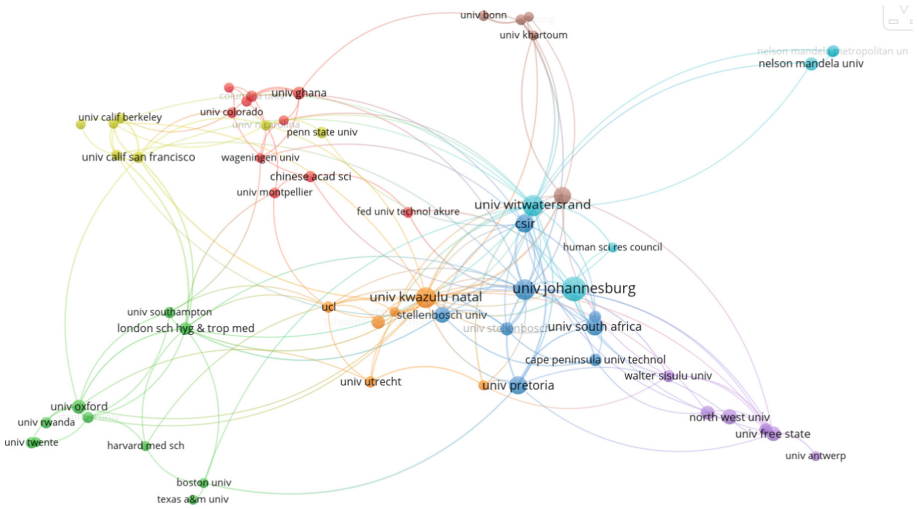

Fig. 7. Institutions collaboration in fourth industrial revolution publications in Africa.

Table 2. Top ten most productive institutions in the research of 4IR in Africa.

Rank	Institutions	Publications	citations	Total strength of collaboration	Country
1	University of Johannesburg	87	816	19	South Africa
2	University of Witwatersrand	52	370	46	South Africa
3	University of KwaZulu Natal	48	359	43	South Africa
4	University of Cape Town	47	327	39	South Africa
5	University of South Africa	31	25	11	South Africa
6	University of Pretoria	30	117	22	South Africa
7	CSIR	30	292	20	South Africa
8	University of Western Cape	27	176	17	South Africa
9	Stellenbosch University	21	154	12	South Africa
10	North -West University	19	72	5	South Africa

The institution with the highest number of publications is the University of Johannesburg. Though the University of Johannesburg is the leading institution in 4IR in Africa, it is not relatively collaborative. The top 11 most contributing institutions are from South

Africa, and these include the University of Witwatersrand, the University of KwaZulu Natal, the University of Cape Town, the university of South Africa, the University of Pretoria and Council for Scientific and Industrial Research (CSIR). This is not surprising to see because South Africa was identified as the most contributing country in fourth industrial revolution publications in Africa as shown in Fig. 4 above. These institutions are also very collaborative. The university of Witwatersrand is the most collaborative institution with a total collaboration strength of 46. It is followed by the University of KwaZulu Natal, the University of Cape Town, and the University of Pretoria with total collaboration strength of 43, 39 and 22, respectively. These South Africa institutions have strong collaboration among themselves, and they also have strong collaborate with other African institutions and institutions abroad. For instance, the University of Witwatersrand shows strong collaboration with the University of Khartoum in Africa and the University of Manchester in England as depicted in the light blue cluster.

Authors Co-authorship Analysis

There are 3337 authors who contributed to the fourth industrial revolution literature in Africa according to WoS. To create the authors co-authorship visualization map only authors with minimum of three papers were considered and 63 authors met the threshold. In the co-authorship map, the relatedness of authors is based on the number of papers co-authored [63]. The authors with a strong co-authorship are clustered together. Figure 8 below illustrates the author co-authorship map.

Fig. 8. Authors co-authorship in fourth industrial revolution publications in Africa.

Based on the outcome of co-authorship analysis as illustrated in Fig. 8 above, there are 30 clusters. Fifteen of these clusters consist of one author per cluster, indicating that the author has not collaborated with other authors. The high number of clusters and small number of authors in the clusters indicate limited collaboration among the authors in 4IR publications in Africa. For instance, authors such as Kotze Eduan, Ngoepe Mpho, and Van Niekerk Adriaan have contributed significantly to 4IR literature, but they are the least collaborative authors in this literature. The red cluster has the highest number of authors, and these include Masinde Muthoni, Madhaudhi Tafadwanashe, Adam Elhadi and Mutanga Onisimo. These are also the most contributing authors in the field of 4IR in Africa as indicated by the bigger circle in the map. Another cluster containing many authors is the blue cluster with six authors that include Dube Timothy and Mudereri Bester Tawona. The author with the strongest collaboration is Mutanga Onisimo collaborating with six authors with a total collaboration strength of 17. The results suggest that generally the most contributing authors are also very collaborative.

Authors Co-citation Analysis

In the author co-citation map, the relatedness of the authors is determined by the number of times the authors are cited together [63]. Authors' co-citation determines the knowledge structure or different subfields in specific research field and identifies the most influential researchers and their interrelationships [64, 65]. Authors meeting the threshold of 10 times minimum of citations were considered, and 182 authors met the criteria. Figure 9 depicts the author' co-citation map with eight clusters. The most influential authors in 4IR research in Africa include the World Health Organization (WHO), The world bank, Breiman, I., Schwab, K., Bag, S., Kuhn, M., and Mutanga, O.

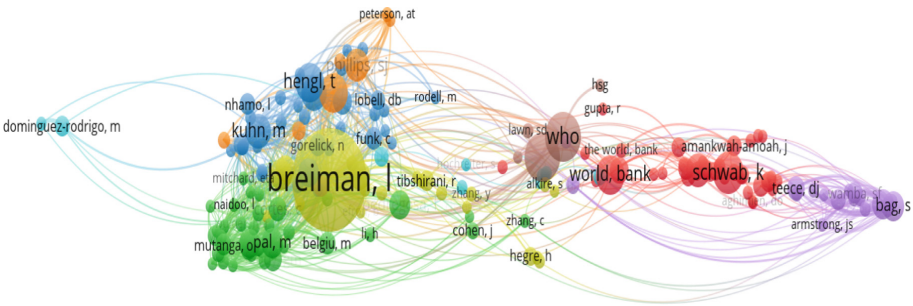

Fig. 9. Authors co-citation visualization map on 4IR publications in Africa.

Key Words Co-occurrence Analysis

Keywords co-occurrence was used in this research study to reveal the 4IR technological trends, hot spots, and gaps in fourth industrial revolution. In a key words co-occurrence map, the relatedness of the keywords is based on number of times the keywords appear together in a paper[63]. Figure 10 shows the keywords co-occurrence map.

The keywords with high frequency of appearance in the literature are represented with bigger circles to show dominance. The keywords that appear together are placed in

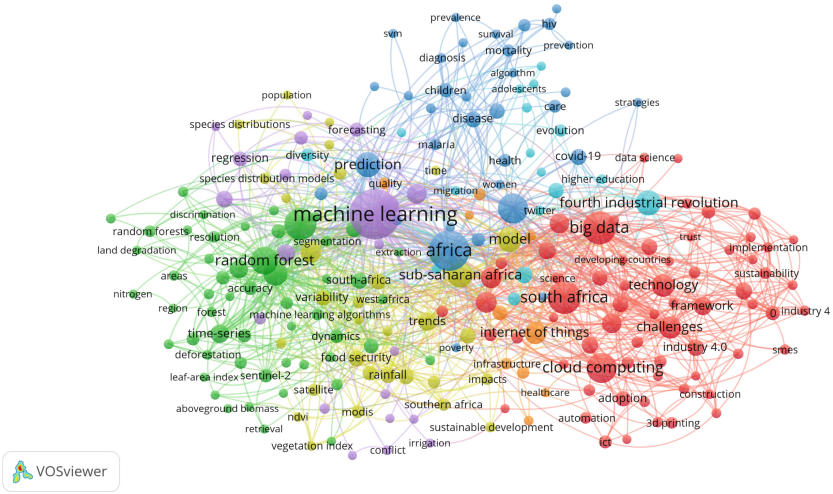

Fig. 10. Key words co-occurrence visualization map on 4IR publications in Africa

one cluster. There were 4346 keywords in fourth industrial revolution in Africa as per WoS, and only keywords that appeared four times or more in the WoS database were considered. Consequently, only 306 were included in the keywords co-occurrence analysis. The keywords were grouped into seven clusters. The biggest cluster (red cluster) consisted of 81 keywords which include industrial 4.0, South Africa, COVID-19, Robotics, internet of things, sustainability, smart cities, and block chain. The green cluster is the second largest cluster with 75 keywords such as classification, image classification, random forest, west Africa, satellite image and patterns. The orange cluster has the least keywords, 14 keywords, which include Africa, farmers, poverty, text classification and democracy.

The keywords denoted with bigger circles are the keywords that have received most attention from researchers in fourth industrial revolution research in Africa. These keywords, therefore, indicate possible research hot spots in fourth industrial revolution research in Africa. The keyword that appeared most was machine learning denoted with a biggest circle. Other prominent keywords include South Africa, classification, artificial intelligence, prediction, random forest, cloud computing and Sub Sahara Africa. Research areas that may have received the least research attention include smart cities, text classifications, block chain, ecosystem service, k-means clustering, energy consumption, policy, health care, sustainable development goals, and precision agriculture. These words are represented with small circles to denote the low frequency of occurrence.

To further understand Fig. 10 above, the top 20 keywords in the literature of fourth industrial revolution in Africa as per WoS are shown in Table 3.

These keywords suggest fourth industrial revolution themes and areas of applications that have been significantly researched in Africa. The keyword with the highest frequency is Machine Learning, followed by Africa, Big data, and South Africa. According to Table 3, the fourth industrial revolution themes or technologies that are most explored include Machine learning, Africa artificial intelligence, big data, remote sensing, cloud

Table 3. Top 20 keywords in fourth industrial revolution literature in Africa.

Rank	Keywords	Frequency	Rank	Keywords	Frequency
1	Machine learning	151	11	Fourth Industrial Revolution	38
2	Africa	98	12	model	37
3	Big data	66	13	Remote sensing	35
4	South Africa	66	14	challenges	29
5	Classification	62	15	Internet of Things	29
6	Artificial intelligence	54	16	performance	27
7	Cloud computing	54	17	Climate-change	27
8	Random forest	46	18	impact	26
9	prediction	39	19	management	24
10	Sub-Sahara Africa	38	20	Deep learning	24

computing, Random Forest (machine learning) and Internet of Things. The keywords in Table 3 suggest the use of fourth industrial revolution in Africa to be mainly for prediction and classification. It is interesting to note that keywords such as climate change have been widely researched in the fourth industrial revolution in Africa. On the other hand, it is not surprising to see South Africa as the top four leading keyword in Fourth Industrial Revolution in Africa. The previous analyses such as in Figs. 4, 6 and 7, and Table 2, have already pointed out South Africa as a dominating country in fourth industrial revolution research in Africa.

4 Discussion

4.1 State of Fourth Industrial Revolution Research in Africa

The results indicate a gradual growth in fourth industrial revolution publications between 2011 and 2022 in Africa, with a peak of 227 publications in 2021. The significant growth in the publications intensified between 2016 and 2017. The upsurge in the number of publications in 2016 and 2017 may be in part attributed to the contribution made by Schawb Klause in this field in 2017 with his book titled "The fourth Industrial Revolution" [2]that popularized the term fourth industrial revolution and possibly triggered more interest in research in this field. Most of the publications in 4IR in Africa are mostly journal articles and proceeding papers from environmental science, remote sensing, computer science, telecommunications, and multi-disciplinary science. The disciplines such as Sport Sciences, Nuclear Science Technology, History, Criminology Penology, Family Studies, and Pharmacology Pharmacy are under-represented in fourth industrial revolution literature. This calls for more research in fourth industrial revolution in these disciplines.

South Africa is the major contributing country in 4IR publications with almost half of African publications (49.9%) originating from its institutions. South African institutions are the most productive and collaborative, with most publications coming from the University of Johannesburg and the University of Witwatersrand. These findings concur with results from bibliometric studies conducted previously [60, 66, 67]. This, therefore, marks a remarkable growth by South Africa in the research studies conducted in Africa. Even though South Africa faces challenges in 4IR[10], it has shown some advancement in infrastructure and investments in research which can explain its high research output especially in 4IR. For example, South Africa has an ample number of higher education institutions and independent research institutes undertaking research in different disciplines [68]. Sutherland [10], and Ayentimi and Burgess [12] emphasize that there is a dire need in Africa to ensure proper infrastructure, and a sufficient supply of skills to boost 4IR. Countries like Lesotho represented with a small circle in Fig. 6, have one publication in 4IR as per data from Wos. On the other hand, countries such as Swaziland are not presented at all. Countries like Lesotho have limited resources, poor infrastructure which can impede their 4IR developments and research outputs [69]. Moreover, Lesotho collaborates only with South Africa in 4IR research as seen in Fig. 6. The literature has highlighted the poor infrastructure, unavailability of resources and low collaboration network as major hindrance in research output.

Even though South Africa is the most productive country in 4IR research in Africa, most of the countries in the top 10 leading countries in 4IR in Africa are from Europe and North America. [70], explains underrepresentation of African in African studies as partly due to imbalance distribution of global research funds. For example, from USD 1.51 trillion research grants from 521 organizations around the world, African institutions receive only 14.5% for climate research while European and North American institutions receive 78% funding for climate research on Africa [70].

The most contributing authors in the 4IR publications include Bags, S., Mutanga, O., and Amad, E, while the most influential authors include WHO, WHO), The world bank, Breiman, I., Schwab, K., and Bag, S. The findings also indicate low collaboration among the countries, institutions, and authors in this field. Mbaye *et al*., [45]and, Yang *et al.,* [71]emphasize the importance of collaboration in research especially on multidisciplinary areas such as 4IR. Literature pointed out inadequate research collaboration networks as one of the factors that Africa contributes less than 1–1.5% to the global research output [50].

4.2 4IR Trending Technologies and Research Trends in Africa

From the bibliometric analysis the following fourth industrial revolution themes stood out in the fourth industrial revolution literature in Africa: Machine learning (deep learning, random forest), artificial intelligence, Internet of things, big data, remote sensing, cloud computing. Additionally, the keywords co-occurrence analysis also highlighted the following words as the trending research keywords in fourth industrial revolution research in Africa: South Africa, classification, prediction, climate change, challenges, and Sub Sahara Africa. These findings suggest Machine learning, artificial intelligence, internet of things, big data, remote sensing, cloud computing to be the fourth industrial

revolution technology trends in Africa. Moreover, the findings highlight that the application of fourth industrial revolution technologies in Africa to be mostly for predictions and classification purposes and to tackle climate change challenges. For instance, the study by [60] pointed machine learning as a tool used for drought prediction in Africa. On the other hand, South Africa appearing among the trending keywords highlights again the dominance of South Africa in fourth industrial revolution research output in Africa. Moreover, there are also several research studies that built prediction machine learning models to address some of the prominent challenges in Africa such as infectious diseases [39]. This can explain the trending of 4IR technologies such as artificial intelligence and machine learning.

4.3 Research Gaps and Future Research Directions

- Future studies should explore 4IR technologies such as robotics, block-chain, quantum computing, virtual reality, 3-D printing as they are under-researched in Africa. Even though these technologies were included in the search strings for paper retrieval as depicted in Sect. 2, they appeared less than eight times in the retrieved data while some keywords such as quantum computing had zero appearance.
- The fourth industrial revolution technologies should also be extended in areas such as ecosystem service, energy consumption, health care, sustainable development goals, and precision agriculture. Unlike prediction and classifications, these words have not been explored significantly in 4IR research in Africa. The keyword, policy also appeared under-researched in 4IR in Africa. Naidoo[72], Sutherland [10], and Ayentimi and Burgess [12] emphasize that there is a need in Africa to ensure proper policy in 4IR to promote 4IR in Africa.
- Disciplines such as Sport Sciences, Nuclear Science Technology, Criminology Penology, Family Studies, and Pharmacology Pharmacy are under-research disciplines in 4IR in Africa as reported in Sect. 3.1. Future studies need to explore 4IR technologies in these disciplines.
- Future studies should be collaborative work. There is a limited research collaboration among the African institutions and authors in 4IR research as pointed in Sect. 4.1. Fourth industrial revolution can be viewed as transdisciplinary that requires knowledge from different disciplines. This therefore calls for, among many, collaboration between scholars in various disciplines and experts from the industries to bring in different expertise necessary to boost the research output in fourth industrial revolution in Africa.

5 Conclusion

There has been a gradual growth in research publications on 4IR in Africa between 2011 and 2022. South African institutions dominate the 4IR publishing space, contributing almost half (49%) of all research outputs. The results also suggest limited collaborations among African researchers in 4IR research which calls for research capacity building. Most research themes in 4IR research in Africa revolve around artificial intelligence, machine learning, big data, internet of things for predictions and classification purposes.

Research trends in 4IR in Africa include South Africa, classification, prediction, climate change, challenges, and Sub Sahara Africa. The findings from this study suggests that there are limited research efforts in areas such as robotics, quantum computer, virtual reality, and disciplines such Sport Sciences, Criminology Penology, Family Studies in 4IR in Africa.

Future studies may also incorporate other dataset from databases such as Scopus and Google Scholar for a more comprehensive review. Results from this research study can be a valuable resource to researchers, practitioners, policy makers and research funding agencies interested in 4IR research in Africa. This research study provides knowledge and grasp the research characteristic of 4IR research studies in Africa.

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